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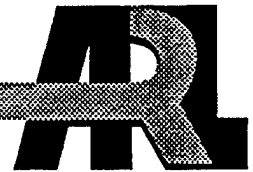
Real-Time Thermal Risk Assessment for the Dismounted Soldier

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13. ABSTRACT (Maximum 200 words)

This report discusses a real-time thermal risk assessment system for the dismounted soldier. This system has been jointly developed by the U.S. Army Research Laboratory and the U.S. Army Research Institute for Environmental Medicine. It is capable of providing work-to-rest ratios, water consumption requirements, and cold survival times that can be used to help prevent soldiers from becoming hyperthermic or hypothermic. The information can be generated over a region the size of a battlefield. The system is comprised of three primary software modules. One module generates high-resolution gridded weather data from any point measurement data available in the region of interest. The other two modules calculate the heat strain and cold survivability parameters. They require the gridded weather data and the data related to the soldier's physical condition, clothing, and activity levels as input. The system is currently undergoing operational test and evaluation at Camp James E. Rudder on Elgin Air Force Base, FL.

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Preface

This report discusses a real-time thermal risk assessment system for the dismounted soldier. This system has been jointly developed by the U.S. Army Research Laboratory and the U.S. Army Research Institute for Environmental Medicine. It is capable of providing work-to-rest ratios, water consumption requirements, and cold survival times that can be used to help prevent soldiers from becoming hyperthermic or hypothermic. The information can be generated over a region the size of a battlefield. The system is comprised of three primary software modules. One module generates high-resolution gridded weather data from any point measurement data available in the region of interest. The other two modules calculate the heat strain and cold survivability parameters. They require the gridded weather data and the data related to the soldier's physical condition, clothing, and activity levels as input. The system is currently undergoing operational test and evaluation at Camp James E. Rudder on Elgin Air Force Base, FL.

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Executive Summary

A real-time thermal risk assessment system that can be used to support the dismounted soldier has become a reality through a partnership development effort between the U.S. Army Research Laboratory Battlefield Environment Directorate and the U.S. Army Research Institute of Environmental Medicine. This software system is designed to provide decision makers with information needed to help prevent soldiers from experiencing hyperthermal and hypothermal conditions. This information includes values for thermal risk parameters such as work-to-rest ratios and cold survival time. These parameters can be calculated and visually displayed for a region the size of a battlefield. Operationally this system is intended to be used as a training management tool or as an intelligence planning tool for training simulations and actual operations. Its application as described in this report pertains to its use as a training management tool. The software is currently undergoing operations test and evaluation at Camp James E. Rudder on Eglin Air Force Base, Florida where Army Rangers undergo swamp training.

The thermal risk assessment system has a modular software architecture which has been a major asset for expediting its overall development and evaluation. The system is presently configured with three primary modules.

The first module is called MERCURY. It provides graphical user interface capabilities; ingests weather, terrain and land-use data for the region of interest; and outputs uniformly gridded, high resolution (as high as 1 km horizontal resolution) weather data that is needed as input by the other two modules. One of MERCURY's major utilities is its ability to rapidly generate gridded data using point measurements that do not adequately capture the variability of weather conditions over a region of interest. This capability is accomplished through an "intelligent' interpolation methodology that uses a combination of rules for adjusting the weather data to changes in elevation and land use. MERCURY can display the gridded weather data as contour overlays that have a map background generated from the elevation or land-use data for the region of interest. The weather parameters most critical for thermal risk assessment are the ambient temperature, wind speed, relative humidity, and solar insolation.

The second module calculates parameters useful for preventing heat strain. It consists of a series of predictive equations that relate core body temperature responses to various work regimes, clothing ensembles, states of acclimation, physical attributes, and weather conditions. It outputs values for tactically significant parameters such as probability of causality, work-to-rest ratios, maximum work time, and water consumption requirements. MERCURY can display the output as a color-coded overlay.

The third module is a mathematical model that predicts survival time in the cold. It defines the end of survival as the point when the body's core temperature reaches a value of 30 °C. The model was developed by the Defense and Civil Institute of Environmental Medicine located in Ontario, Canada. It allows the ambient condition to be either air or water. The model outputs survival time in three categories: less than 1 h, 1 to 24 h, and greater than 24 h. The output is color coded when displayed by MERCURY.

The complete software system was implemented on a Sun workstation using the UNIX operating system and the X11/Motif windowing environment. Future development work is expected to include the addition of new capabilities such as handling partial immersion situations and being able to input numerical weather prediction data.

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1. Introduction

The dismounted soldier is often engaged in a wide spectrum of activities that are affected by the weather. Examples of these activities include paradropping, ground mobility, night vision, and otherwise performing in conditions capable of producing heat or cold injury.

The U.S. Army Research Laboratory's Battlefield Environment (BE) Directorate and the U.S. Army Research Institute of Environmental Medicine (USARIEM) are jointly developing a computer modeling system for the real-time assessment of heat strain and cold survivability over a battlescale area (approximately 250 by 250 km), as part of an effort to better prepare the soldier for possible adverse weather effects. This modeling system will serve as a training management tool, as part of a training simulation, and as an intelligence planning tool for military operations.

This report describes the three modules that comprise the modeling system. The report begins with the MERCURY module responsible for ingesting and processing the weather and terrain data. It then describes the heat strain and cold survivability modules that use MERCURY's output to calculate the effects of heat and cold exposure. The report also includes a discussion of the developmental work planned for the future .

2. MERCURY Module

MERCURY's primary mission is to accurately grid meteorological data over a battlescale region using data collected from point measurements that may number less than 10. This function can be of great value to the military. It provides a high-resolution data grid throughout the battlescale region of interest. The high-fidelity data has been adjusted for the localized weather effects attributable to terrain and land use influences. This procedure is automated and reduces the amount of manpower and time necessary for the effort.

2.1 Model Design and Performance Specifications

MERCURY is designed to operate in a stand-alone mode or as a module within a larger modeling system. It consists of six major sub-modules or directories (table 1). Each of these sub-modules are divided into sub-modules or files that perform specific functions. The modularity facilitates software modification and minimizes the data input and output issues that arise when combining this model with other computer models.

MERCURY is written in C language and runs under the UNIX operating system using the X11/Motif window environment. The software was developed on the Sun Sparc IPX workstation.

Table 1. MERCURY's six major sub-modules

Sub module	Description
Interface	Displays the weather, terrain, heat strain, and cold strain information in windows.
Sgx	Provides simple graphics routines for X-windows processing.
Utility	Performs input/output functions; contains general utility algorithms.
Terrain	Reads, scales, and grid processes the raw terrain elevation and land use data.
Weather	Reads files with raw weather data and creates new files with data format necessary for analyses routines.
Analyses	Calculates grid point values of weather variables and performs subgrid interpolation of data.

The calculations for gridding the meteorological data are performed using expert system technology with more traditional mathematical algorithms and routines. The expert system technology is incorporated as "if-then-else" type rules that are used for decision making. These decisions range from selecting the appropriate coefficients for a mathematical algorithm to identifying the met stations that have data most representative of an area for which no meteorological data exists. The mathematical algorithms are analytical and vary in size from a few lines to approximately 300 lines of code.

Two major performance requirements for MERCURY are rapid execution and the ability to generate a high-resolution (a grid spacing of 1 and 10 km) meteorological data base with data that often does not adequately reflect the spatial variability in the weather conditions over the battlescale area of interest. Most of the variability is attributed to changes in terrain elevation and/or land use. Rapid execution is defined as the ability to calculate all relevant met parameters at a user specified location within 15 s.

The performance requirements are met by combining the advantages of standard analytical methods with the advantages inherent in expert system technology. Analytical methods offer the advantage of requiring only limited input data and providing quick computation not possible with more sophisticated numerical models. Expert system technology allows for skilled application of the analytical methods (for example, selecting the appropriate lapse rate for adjusting temperature) necessary for achieving high resolution.

2.2 Data Input Requirements

MERCURY requires weather, land use, and terrain elevation data as input. The weather data is the most dynamic data over time and therefore requires the most frequent updating. Ambient temperature, wind speed, relative humidity, and direct solar radiation are needed to calculate heat strain and cold survivability. These parameters are highly variable with time and should be updated hourly. The next most dynamic data is land use. Land use data must be updated with a frequency

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that reveals significant seasonal and cultural changes in land use. The terrain elevation can normally be represented by a static data base.

MERCURY needs the land use and elevation data during its decision making process for extrapolating (gridding) the met parameters. It also uses the two data sets for creating map backgrounds for graphical output.

The Defense Mapping Agency's (DMA) Digital Terrain Elevation Data Level 1 (DTED1) is the preferred source of terrain elevation data. DTED1 data was used because of its high (100m) horizontal resolution and because it was available for most areas of the earth.

The land use data must have a resolution compatible with the elevation data. We used land use data derived from Landsat satellite imagery. The Landsat data offers high resolution (30 m) and is usually the most current. However Landsat-derived, land-use data is not readily available for many regions of the world and must be processed by the U.S. Army Waterways Experiment Station. An alternative source of this data is the vegetative theme data from DMA's Interim Terrain Data (ITD). Although we have not used the ITD data, it has the appropriate resolution and land use categorization necessary for our applications. ITD is presently available for limited regions of the world. However, ITD is a prototype for Tactical Terrain Data which is expected to become a standard data set, offering wide coverage of the world.

MERCURY is also capable of displaying Arc Digitized Raster Graphics (ADRG) data as a map background. However, this data only constitutes an electronic map background and cannot be used computationally by any of MERCURY's algorithms.

MERCURY has been designed to automatically ingest the meteorological data from the Army's Integrated Meteorological System (IMETS) or a system similar to IMETS in a tactical environment. Table 2 lists the met related parameters MERCURY is currently able to ingest.

Table 2. Meteorological data input

Parameter	Unit/code
Station	Three-letter identifier
Latitude	Degrees north or south
Longitude	Degrees east or west
Year	Last two digits of year
Month	Month of year (00-12)
Day	Day of month (00-31)
Hour	Hour of day (00-24)
Elevation	Meters above Mean Sea Level
Temperature	Degrees Fahrenheit
Dew point	Degrees Fahrenheit
Wind direction	Degrees clockwise from north
Wind speed	Knots
Pressure	Millibars
Visibility	Miles
Precipitation (36 h)	Inches
Precipitation (24 h)	Inches
Extreme temperature	Degrees Fahrenheit
Minimum temperature	Degrees Fahrenheit
Maximum temperature	Degrees Fahrenheit
Cloud types	For low, medium, and high clouds (categories 0 to 9 per level)
Solar radiation	Watts per squared meter
Snow	Inches
Cloud cover	Clear, scattered, broken, overcast, obscure
Cloud level	Feet
Cloud level number	Number of cloud levels
Present Weather	Categories 00-99

The current prototype version of MERCURY has terrain and weather data sets for the three regions (table 3).

Table 3. Regions selected for prototype

Region	Latitude (N)	Longitude	Grid spacing (km)
Los Angeles	33.0 to 35.0	117.0 to 119.0 W	3.0
Fulda Gap	50.0 to 52.0	8.5 to 11.5 E	3.6
South Korea	37.0 to 37.5	127.2 to 127.7 E	0.3

These regions were selected because they have variable landforms and land use that create very localized weather conditions. They have sufficient weather and terrain data available, and in the case of South Korea, its potential military significance. This selection criteria is necessary to evaluate MERCURY's analysis capability and to demonstrate its potential application. The grid spacings refer to the resolution of the processed elevation data. The grid spacing can easily be changed by the program user, but cannot be smaller than the resolution of the original elevation data set.

2.3 Data Processes

MERCURY processes three primary data sets: terrain elevation, land use, and met. Once a region of interest is selected (for example Los Angeles, Fulda Gap, and South Korea), the first data processing steps involve loading the elevation and land use data into a file with a gridded format.

When loading the DTED1 for regional requirements, the user must identify the latitude and longitude coordinates of the region's southwest corner, indicate the number of grid points which run north and east from the southwest corner, and specify the distance in degrees between the grid points. The resolution of the data cannot be higher than the original resolution of the DTED1 (3 arc s or about 100 m).

The land use data must be read from a raster file because it is loaded identical to the elevation data. MERCURY's meteorological, data spreading routines work more accurately if the land use resolution is similar to the elevation data resolution.

The newly created grid of elevation data can be used as input to the MERCURY program for calculating the slope of the terrain. The slope is calculated in degrees and stored in a gridded format identical to that for the elevation data. The slope data is used later by another MERCURY program that identifies terrain objects.

The terrain objects program identifies terrain features (usually mountains) thought to have a significant impact on the local met conditions. Terrain features are

identified according to slope, areal extent, and relative height. The program user can change the values for these criteria. Typical values are a slope of greater than 5°, an area of at least 25 km², and an elevation of at least 300 m above the lowest elevation point in the region of interest. A grid point is determined to be part of a terrain object if it meets all three criteria or has at least one of its four nearest grid points meet all criteria. All the grid points that are part of a terrain object are stored in a gridded data file with the same format as the elevation data.

The surface meteorological data is spread over a grid with a resolution no higher than the grid resolution of the elevation and land use data. The grid resolution of the meteorological data can be specified by the user. For example, when MERCURY processes the prototype data for the Los Angeles basin, it creates a gridded meteorological data field with a resolution of 15 km. Using this initial gridded data field, MERCURY can perform a distance weighted interpolation (using data from the four nearest grid points) to output meteorological data with the same resolution as the elevation data. MERCURY can generate a gridded data field for upper air data, but present application requirements require the focus to be on developing routines for gridding surface data.

MERCURY's analysis routine for generating the gridded meteorological data includes the following procedures:

1. The user defines the resolution of the grid field. The resulting grid points located inside one grid spacing of a weather station, with reported data in the previous 2 h, are classified as nonisolated. All other grid points are classified as isolated.

2. In the case of isolated grid points, a search for representative weather stations is undertaken using heuristics. For a weather station to be deemed representative, the distance between the weather station and the grid point location cannot exceed two grid points and must have similarity between the grid point and the weather station location. The similarity qualification means that the grid point and the weather station must be in the same significant terrain object or outside all significant terrain objects.

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3. Data is then generated for each of the isolated grid points that have representative weather stations. Data is generated by correcting the reported data for any expected changes caused by elevation and land use differences between the locations of the reporting station and the isolated grid point. The corrections are made by using rule structured algorithms. Fields describes (appendix D) the algorithms MERCURY has available for correcting the wind speed, wind direction, ambient temperature, and ambient pressure. [1] Additional rule based algorithms have been implemented for spreading cloud cover and fog. Corrections are currently not applied to other variables such as solar radiation. If data exists from more than one representative weather station, the data for the isolated grid point is determined by distance weighted averaging the corrected station data.

4. Data (for isolated and nonisolated grid points without representative stations) is calculated by distance weighted averaging the station data and the grid point corrected data.

5. Values for the present weather conditions are those reported by the nearest reporting station. [1]

MERCURY contains a self-testing sub-module for evaluating system performance. The sub-module can use real-time data or archived data. In the real-time mode, it can be run continuously and accumulate error statistics over time. The evaluation procedure requires excluding a reporting station and calculating the values of its weather variables as if it were a grid point. Then the error between the calculated and measured values is calculated for each weather variable. To get a comparison, the grid point calculations are also performed using a standard distance weighted objective analysis routine. Various summary statistics, such as the average absolute error and the standard deviation, can be output.

Steve Kirby conducted an evaluation of MERCURY's temperature gridding algorithm using Los Angeles basin data collected from 20 reporting stations February 3 through 28, 1992. [2] His evaluation, which used both absolute error

and standard deviation summary statistics, indicates that MERCURY performed about 14 percent better than standard objective analysis.

An earlier study that examined MERCURY's temperature, dew point, wind speed, and wind direction gridding algorithms indicates that MERCURY's performance was substantially better in relation to standard objective analysis for all four weather variables. [3] For example, the average percent of absolute error for the MERCURY-generated dew point temperature had less than one-third the errors associated with the standard objective analysis method. However this evaluation only examined two of the 20 reporting stations in the Los Angeles basin.

2.4   Information Output Using the Graphical User Interface

Figure 1 shows the MERCURY graphical user interface (GUI). The GUI consists of a two-pane window. The top pane is a 3-D rendering of the terrain elevation data for the selected region (the Los Angeles basin area). The bottom pane displays the overlays. They can be displayed with a map background or a gray scale relief background. The map background is created from ADRG or similar data; the relief background is created from DTED1. A legend defines the gray scale in terms of meters above sea level. The location of the area shown is identified at the very top of the GUI. Directly below the location identifier is the menu bar with four popup menus. The File menu is designed to select a new region of interest or to exit the program. Options under the Terrain menu are used to select the background for the overlay, (for example, either a 2-D ADRG map image or a 2-D grayscale elevation relief map). The Utilities menu has three functions. The first function allows the user to toggle on and off the reporting weather stations. Figure 1 shows the weather station locations as icons containing a three-letter code. Functions two and three execute the heat strain and cold survivability models. The "Export" menu contains functions responsible for creating image files that allow the GUI to be exported and viewed by several widely held geographic information systems.

The latitude and longitude coordinates of any point on the map or relief background can be obtained by placing the mouse cursor on that point and clicking on the middle button. Clicking on the left mouse button displays a box

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(figure 1) that shows the values for seven weather parameters with the location coordinates, the date and time for which the values are valid, and the elevation at the cursor location. Other weather parameters can also be shown in this box.

MERCURY can produce two terrain related overlays and six met related overlays. When the MERCURY module is connected to the heat strain and cold survivability modules, the total number of overlays increases to 13. The heat strain and cold survivability overlays are discussed later in the report.

The two terrain overlays are land use and terrain objects. Using a color code, the land use overlay displays the following 10 land-use categories: urban, agriculture, forest, rangeland, water, barren land, wetlands, tundra, perennial snow, and other. The terrain objects overlay identifies areas in red that meet specified slope, elevation, and areal extent criteria. This overlay is primarily intended to locate meteorologically significant terrain features.

The six meteorological parameters for which overlays are generated include: cloud cover, fog, temperature, humidity, wind speed, and ambient pressure. The overlays use the gridded data files generated by the various algorithms used to grid the data over the region of interest. Cloud cover and fog are depicted through color shading. The overlays for temperature, humidity, wind speed, and ambient pressure are contoured. There are eight color coded contour bands generated. A legend defines the range of values for each color band. The contour interval is determined by dividing the difference between the minimum and maximum values of a particular parameter at a given time by eight.
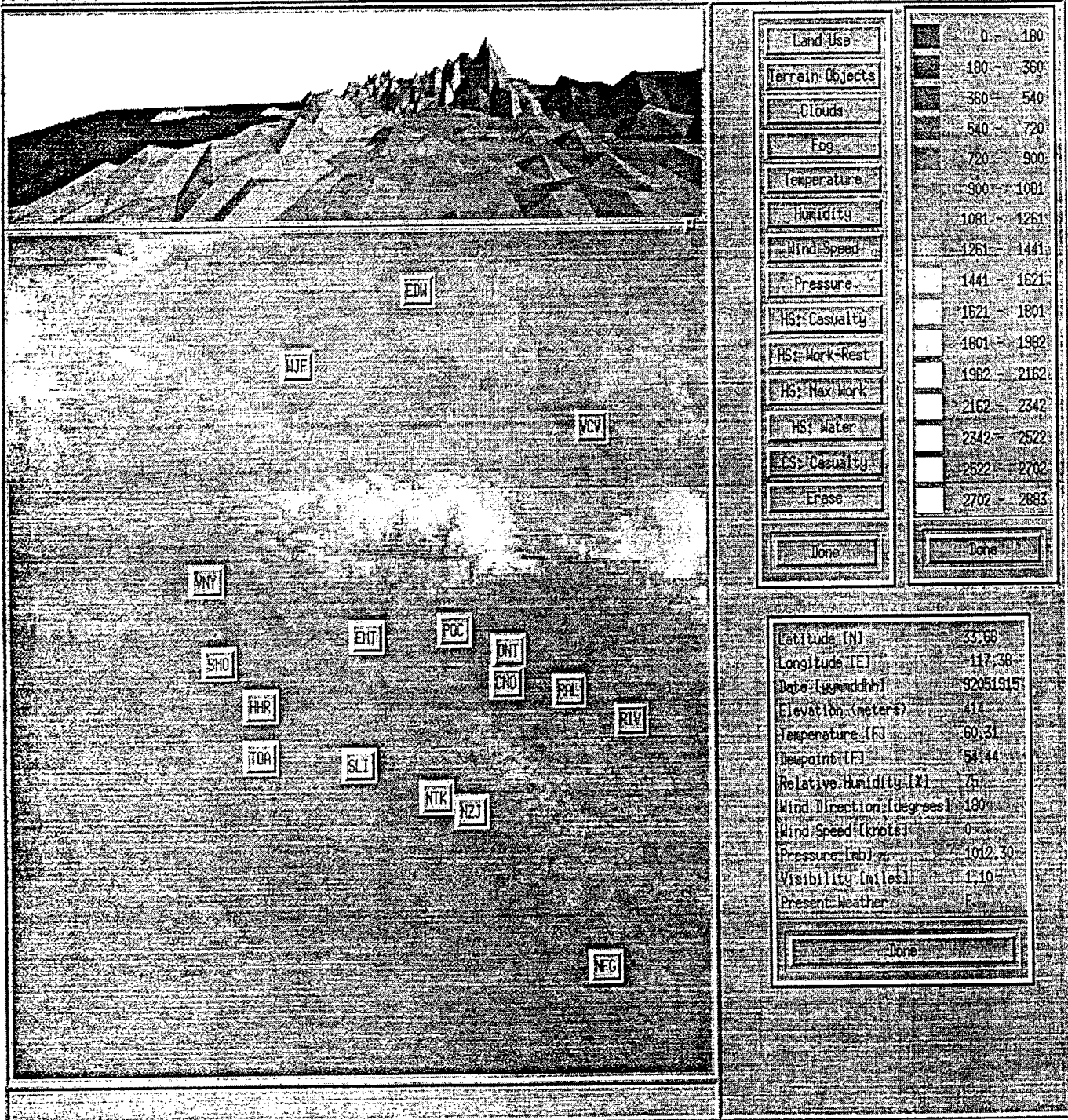
Figure 1. MERCURY graphical user interface.

3. Heat Strain Module

The heat strain module consists of a series of predictive equations that relate core body temperature responses to various work regimes, clothing ensembles, states of acclimation, physical attributes, and environmental conditions. The model was developed by the USARIEM located at Natick, MA. All the code was programmed in Ada. It compiles on the Sun Ada compiler without any modifications and will compile on any other UNIX computer with few modifications. [4]

3.1 Model Development

The equilibrium core body temperature is a fundamental component of the heat strain model. It is determined through a thermal balance calculation and represents the temperature where the body's heat gain and loss are equal. The major variables in the thermal balance calculation are metabolic heat production, convective, radiant, and evaporative heat exchange. [5]

The meteorological parameters that directly affect the thermal balance and consequently the body's equilibrium core temperature are ambient temperature, relative humidity, wind speed, and solar radiation. Ambient temperature and wind speed affect the convective and evaporative heat transfer rate. Relative humidity is a dominant factor that determines the evaporative heat exchange. The level of radiation is used to calculate the rate of radiant energy transfer.

The model expresses heat strain not in terms of actual equilibrium core temperature, but in the more tactically significant terminology of probability of casualty, work-to-rest ratios, maximum work time, and water requirements. All four expressions can be displayed as overlays selectable from the MERCURY interface. These output products are described later in the report.

3.2 Input Data

The three major categories of input data to the heat strain model are the meteorological parameters, the physiological characteristics of the soldier, and the type of clothing worn by the soldier. All input data is provided by the MERCURY module.

MERCURY provides the meteorological parameters in a gridded format that makes it possible to reflect the spatial variability of heat strain over a battlescale region. Table 4 lists the user selectable values/categories for the physiological and clothing input data necessary to determine equilibrium body temperature. [6]

Table 4. Physiological and clothing input data

Variables	Selection categories	Value
Dehydration (percentage)	Not dehydrated	0.00
	Normally dehydrated (default)	1.24
	Slightly dehydrated	2.50
	Moderately dehydrated	4.00
	Severely dehydrated	6.00
Work activity (Watts)	Very Light	150.00
	Light	250.00
	Medium (default)	425.00
	Heavy	600.00
Acclimation (days)	12 (default)	
Soldier attributes	Height (cm)	180.00 (default)
	Weight (kg)	80.00 (default)
Clothing type	MOPP 0 (default)	
	MOPP 1	
	MOPP 2	
	MOPP 3	
	MOPP 4	

All inputs have been assigned defaults as noted.

Acclimation refers to the number of days a soldier has had to physiologically adjust to any climate change. Typically it takes a person 5 d to achieve 80 percent of the acclimation adjustment and about 12 d to become fully acclimated. [7]

The clothing type is defined in terms of mission oriented protective posture (MOPP). The clothing type determines the amount of insulation measured in clo. Goldman defines one clo unit of clothing and air insulation as allowing 5.55 kcal/m^2•hr of heat exchange by radiation and convection for each 1 °C of temperature difference between the average skin temperature and the ambient adjusted bulb temperature (one-half the value of the air temperature plus the mean radiation temperature). [8]

3.3   Information Output

Numerous field studies have been conducted to establish databases that relate equilibrium core temperature to factors that can manage the risk of thermal injury. The relationships are in the form of accumulative probability distributions. The distributions are used by the heat strain model to calculate the probability of casualty, maximum work time, work/rest cycles, and water consumption requirements. The model uses the MERCURY user interface to output this information.   The information is displayed as color-coded overlays on appropriately scaled map backgrounds.

The probability of casualty overlay can show three levels of probability (table 5) for soldiers that observe no work/rest or water disciplines.

Table 5. Probability of casualty

Color overlay	Probability (%)
Green	<5
Gold	5 to 20
Red	>20

The work/rest overlay shows the ratio of work/rest in minutes per hour of work/ rest discipline required to sustain soldier performance. Table 6 indicates that soldiers working in areas covered with red require more than 30 m of rest/hour to sustain performance.

Table 6. Work/rest ratio

Color overlay	Minutes of work per hour
Red	<30
Gold	30 to 55
Green	>55

The maximum work/time overlay displays the predicted straight time period that a soldier could work before becoming a heat strain casualty if no work/rest or water disciplines are observed. The color red (table 7) indicates areas where a heat casualty could occur after less than three hours of continuous work.

Table 7. Maximum work time

Color overlay	Minutes of continuous work
Red	<180
Gold	180 to 300
Green	>300

The water requirements overlay displays the number of canteens of water (1 canteen = 1 quart) consumed, per soldier per hour, to sustain continuous operations when work/rest disciplines are implemented. Table 8 shows that an area displayed in red requires a water consumption rate in excess of 1.7 canteens per hour.

Table 8. Water requirements

Color overlay	Water consumption (canteens/hour)
Red	>1.7
Gold	0.7 to 1.7
Green	<0.7

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4. Cold Survivability Module

The cold strain module is a mathematical model for predicting survival time (ST) in the cold. The model defines the end of survival as the point when the body's core temperature reaches a value of 30 °C, the temperature where unconsciousness normally develops. The model was developed by the Defense and Civil Institute of Environmental Medicine (DCIEM) in Ontario, Canada. [9] The source code is written in the C programming language.

4.1 Model Development

The DCIEM model is based on the principles of steady-state heat conduction in a single cylinder. The cylinder is comprised of a core and two annular concentric shells representing body fat and skin, and clothing plus still air. The ambient condition can be either air or water. The model distinguishes between the two conditions by assigning different values of insulation to the still boundary layer. However, the model cannot currently handle situations involving partial or repeated immersions.

The model assumes that protection against the cold is uniformly applied to the surface of the body. The model also excludes the body's initial transient response to cold, characterized by vasoconstriction, which usually results in a delay in the fall of body temperature for up to one hour.

The radius used by the model cylinder is 1.5 times larger than the radius that actually corresponds to the volume and surface area of the human body. However, the corrected radius corresponds to the radius of the human trunk and reflects the fact that the surface area of the body (which actually exchanges heat with the environment), ranges between 50 and 80 percent of the total body surface area.

The standard anthropometric values used by Tikuisis and Frim in their ST study are body fat of 14.8 percent, height of 1.74 m, and weight of 74.5 kg. [9] The values were obtained using the body composition measurements of male Canadian Forces personnel.

The model was developed for a sedentary person. Therefore the two sources of heat production were resting metabolism and shivering. Heat production from resting metabolism was assigned a fixed rate of 50 $W \cdot m^{-2}$. The predicted value of heat production from shivering assumes the individual to be healthy and uninjured and does not exceed 200 $W \cdot m^{-2}$.

The model provides two basic situations for determining ST. The first situation occurs when the heat conduction properties of the model largely determine ST because the cold exposure is too severe for metabolic heat production to balance heat loss. The second situation occurs when the depletion time of the energy reserve for shivering governs ST because there is a balance between metabolic heat production and heat loss.

Controlled data for deep hypothermia is unavailable, thus a thorough evaluation of the model is difficult. Exposure to water was selected for calibrating the model because these survival times have been more clearly delineated from accidental immersions than from exposure to cold air. The model was tested against thermoneutrality, nude exposure at 5 °C, and an accidental exposure at -20 °C. There was reasonably good agreement between model predictions and observations for all three conditions. [9]

4.2 Environmental Data Input

The environmental data required as input depends on whether the model is operating in the air or water mode. When the model is operating in the air mode, the required input data is the ambient air temperature and wind speed. Only data on the water temperature is needed when the model is operating in the water mode.

In the model, ambient air temperature affects the rate of steady-state heat loss from the body. Figure 2 is a plot of the model-predicted survival times versus the ambient temperature for various clothing insulation levels, and it examines the magnitude of the ambient temperature effect. For example, a man dressed in clothing with a thermal insulation of 0.5 clo can expect to survive 24 h at 0 °C but

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only 9 h at -10 °C. All the predicted survival times presented in figure 2 assume the wind speed is 2 km·h⁻¹.

The model handles the effect of wind speed by changing the thickness of the still air that represents the outermost layer of the cylinder. The effect of a wind speed increase is to decrease the thickness of the still air layer.
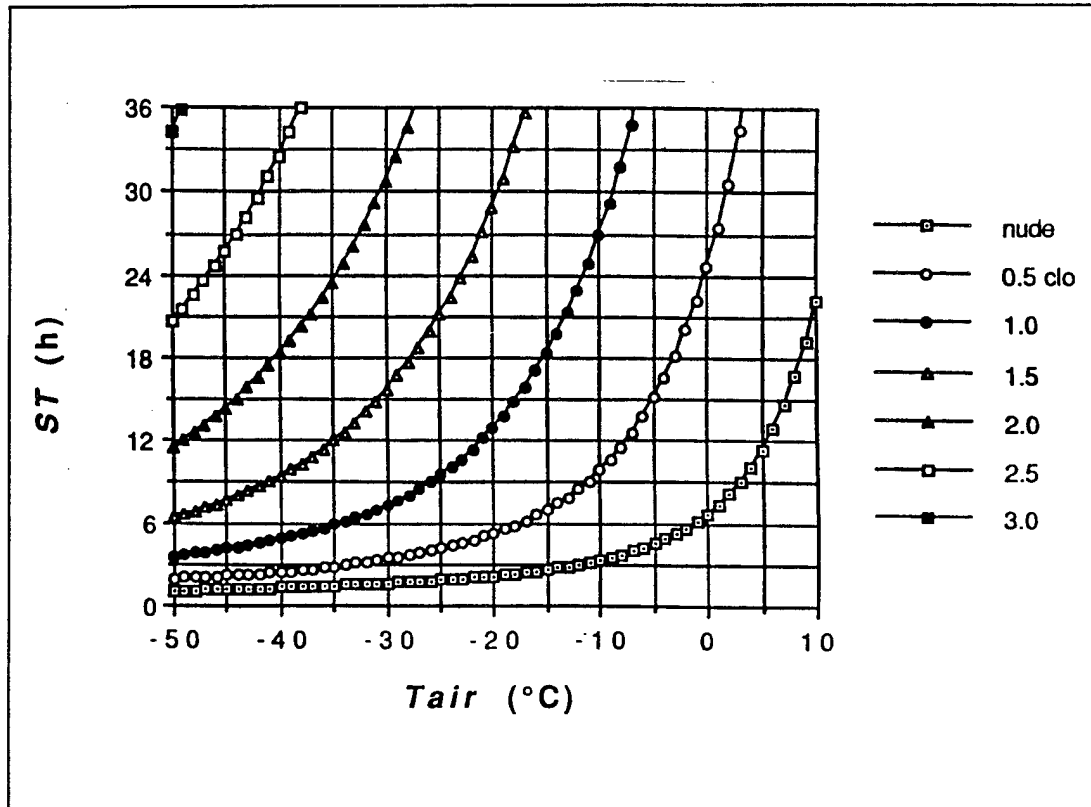
Figure 2. Model-predicted survival times as a function of air temperature and various insulative conditions for a wind speed of 2 km•h⁻¹. [9]

Figure 3 illustrates the effect of the wind speed on predicted survival time. It shows that a person dressed in clothing with 1.5 clo of insulation can survive a -20 °C temperature for 9 h at a wind speed of 20 km/h. It also shows that the survival time of this same person is predicted to increase to 29 h if the wind speed is only 2 km/h. [9]

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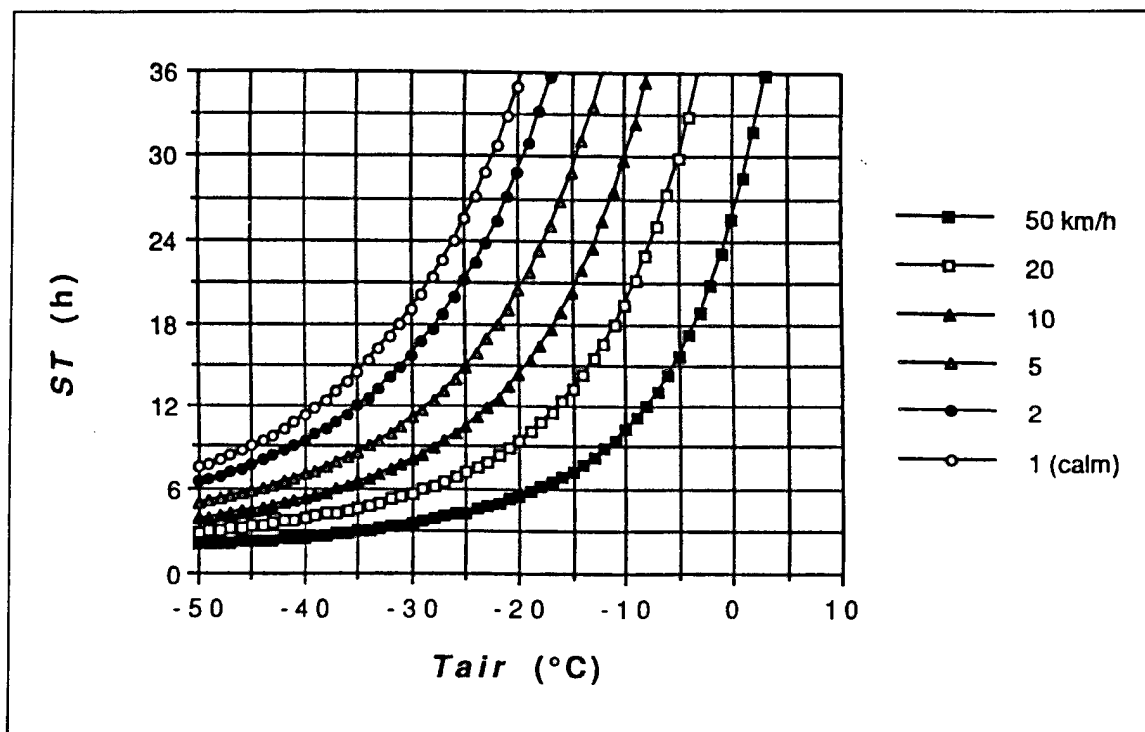
Figure 3. Model-predicted survival times as a function of air temperature and various wind speeds for a clothing insulation of 1.5 clo. [9]

4.3 Information Output

The information output is a color-coded overlay of the predicted survival time. Table 9 shows survival time in three ranges; any area indicated in red is an area in which a soldier is expected to survive less than 1 h.

Table 9. Survival time

Color	Time of survival (hour)
Green	>24
Gold	1 through 24
Red	<1

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5. Future Work

The MERCURY thermal injury prediction system will be installed at Camp James E. Rudder on Eglin Air Force Base. It will be used as a training management tool to help prevent heat and cold injuries from occurring during Ranger training at Camp Rudder. After the initial installation, further capabilities and improvements are expected to be implemented in the prediction system. The data collected on-site will be used to thoroughly evaluate the new capabilities and improvements.

Some of the anticipated capabilities and improvements are:

1) including a model for partial immersion situations;

2) incorporating the effects of solar radiation in the cold survivability model;

3) allowing the user of the cold survivability model to select from a variety of work activity levels, clothing ensembles, and soldier attributes;

4) accounting for the physical condition (for example, nutritional and rest level) of the soldier in both the heat and cold models;

5) using MERCURY to access and process mesoscale forecast data to provide thermal predictions out to 24 h;

6) providing the user the ability to manually input met data;

7) improving the existing routines in all the models in accordance with evaluation results.

6. Summary

A prototype system that automates the task of assessing the risk of thermal injury to the dismounted soldier is now available. It calculates thermal risk associated with heat and cold exposure. The calculations are performed over a battlescale region and have a resolution that reflects the local scale meteorological differences caused by elevation and land use changes; a resolution that is most meaningful to the dismounted soldier. Future development work will extend the scope of the system's capabilities. For instance, there are plans to implement the capabilities to handle partial immersions and to make predictions based upon forecast data.

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Acronyms and Abbreviations

ADRG	Arc Digitized Raster Graphics
clo	clothing type that determines the amount of insulation measured
BE	Battlefield Environment
DCIEM	Defense Civil Institute of Environmental Medicine
DMA	Defense Mapping Agency
DTED1	Digital Terrain Elevation Data Level 1
GUI	Graphical User Interface
IMETS	Integrated Meteorological System
ITD	Interim Terrain Data
MOPP	Mission oriented protective posture
ST	Survival time
USARIEM	U.S. Army Research Institute of Environmental Medicine

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